The Effects of Acute Transcranial Direct Current Stimulation on Attentional Bias in Pedophilic Disorder: A Preregistered Pilot Study

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Abstract: Objectives Individuals with pedophilic disorder (PD) experience personal and interpersonal difficulties and are at risk of sexually offending against children. As such, innovative and empirically validated treatments are needed. Recent studies have indicated that men who have sexually offended against children (SOC) with PD display an automatic attention bias for child-related stimuli as well as reduced activity in the dorsolateral prefrontal cortex (dlPFC), a brain area involved in cognitive control, including control over sexual arousal. In this preregistered pilot study, we are the first to investigate whether acutely increasing prefrontal activity could reduce the putative pedophilic attention bias. Materials and Methods We delivered a single 20-min session of active anodal versus sham transcranial direct current stimulation (tDCS) over the left dlPFC to 16 SOC with PD and 16 matched healthy controls, while they performed a task requiring controlled attention to computer-generated images of clothed and nude children and adults. We collected responses unobtrusively by recording eye movements. Results Our results did not support the presence of the expected automatic attention bias across outcome measures. Nonetheless, we found a response facilitation with child targets in patients and, unexpectedly, in controls, likely due to unwanted salience effects. Active versus sham tDCS reduced this bias across groups, as indicated by a significant group*condition interaction ($p = 0.04$). However, no attentional bias and no tDCS effects on attentional responses to child and adult images emerged following tDCS. Conclusions These results suggest enhanced cognitive control in response to salient stimuli during active tDCS. Thus, to assist future studies on neuromodulation in PD, we provide suggestions for design improvement.

DOI: https://doi.org/10.1111/ner.13285

Originally published at:
Pezzoli, Patrizia; Ziogas, Anastasios; Seto, Michael C; Jaworska, Natalia; Mokros, Andreas; Fedoroff, Paul; Santtila, Pekka (2021). The Effects of Acute Transcranial Direct Current Stimulation on Attentional Bias in Pedophilic Disorder: A Preregistered Pilot Study. Neuromodulation, 24(5):879-889.
DOI: https://doi.org/10.1111/ner.13285

The Effects of Acute Transcranial Direct Current Stimulation on Attentional Bias in Pedophilic Disorder: A Pre-registered Pilot Study

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Abstract

Individuals with Pedophilic Disorder (PD) experience personal and interpersonal difficulties and are at risk of sexually offending against children. As such, innovative and empirically validated treatments are needed. Recent studies have indicated that sex offenders with child victims (SOC) with PD display an automatic attention bias for child-related stimuli as well as reduced activity in the dorsolateral prefrontal cortex (dlPFC), a brain area involved in cognitive control, including control over sexual arousal. In the present pre-registered pilot study, we were the first to investigate whether acutely increasing prefrontal activity could reduce the putative pedophilic attention bias. To do so, we delivered a single 20-minute session of active anodal vs. sham transcranial direct current stimulation (tDCS) over the left dlPFC to 16 SOC with PD and 16 matched healthy controls, while they performed a task requiring controlled attention to computer-generated images of clothed and nude children and adults. We collected responses unobtrusively by recording eye movements. No significant tDCS effect on visual attention to sexually salient stimuli emerged during or immediately after stimulation. From a qualitative perspective, observations were in line with a bias for sexually preferred vs. non-preferred stimuli in patients but not in controls. Importantly, active vs. sham tDCS reduced this bias across outcome measures in patients but not in controls. Based on these preliminary findings, it is worth further investigating the possibility of using brain stimulation as a therapeutic intervention for PD. Methodological improvements were also identified and discussed to assist future research.

Keywords: Pedophilic Disorder/Pedophilia/Child Sexual Offending/Child Sexual Abuse; Transcranial Direct Current Stimulation/Brain Stimulation/Neuromodulation; Dorsolateral Prefrontal Cortex; Cognitive Control/Automatic Attention Bias; Eye Movements.

The Effects of Acute Transcranial Direct Current Stimulation on Attentional Bias in Pedophilic Disorder: A Pre-registered Pilot Study

Pedophilia is characterized by recurrent and intense sexual fantasies, urges, or behaviors involving prepubescent children, and Pedophilic Disorder (PD) is associated with marked distress or impairment as a result (American Psychiatric Association, 2013). PD is an important risk factor for sexual offending against children (Hanson & Morton-Bourgon, 2009). Indeed, approximately half of individuals convicted for sexual offenses against children have PD (Seto, 2013, 2018). Despite the personal and societal cost of PD, the efficacy of available treatments is debated. Behavioral conditioning protocols, such as aversion therapy, have been shown to reduce pedophilic sexual arousal but only in the short term (Barbaree, Bogaert, & Seto, 1995), and empirical research on cognitive behavioral approaches remains inconclusive (Långström et al., 2013). Although pharmacological interventions may be effective (Garcia, Delavenne, Assumpção, & Thibaut, 2013), in the long term, their side effects often result in noncompliance. For example, sexual dysfunctions associated with the use of antiandrogen agents and selective serotonin reuptake inhibitors (SSRIs; Holoyda & Kellaher, 2016) might impede sexual relationships with adult partners. Moreover, the efficacy of combined treatment for self-referred PD patients from the community has been questioned recently (Mokros & Banse, 2019). As a result, new therapeutic avenues should be explored.

An intriguing possibility is to use recent evidence regarding possible cognitive and neurobiological alterations in PD to inform the development of novel treatments. A growing number of studies have shown that men with PD display an automatic attention bias for child-related visual stimuli (Fromberger et al., 2013; Mokros et al., 2013). In the context of sexual preferences, this automatic attention bias is reflected in facilitated initial orienting (e.g., Fromberger et al., 2011; Kagerer et al., 2014) and longer viewing times (e.g., Schmidt, Babchishin, & Lehmann, 2016) for sexually preferred compared to non-preferred stimuli. Given that eye movements are a valid proxy for attentional processes (Zhao, Gersch, Schnitzer, Dosher, & Kowler, 2012), automatic attention bias may be examined with eye tracking. Accordingly, in individuals with PD, eye tracking has been successfully employed to detect attentional preferences for child-related stimuli (Fromberger et al., 2012).

It has been further suggested that this attention bias might be associated with impaired cognitive control over sexual responses (Jordan et al., 2016). In support of this, decreased activity in frontal regions such as the left dorsolateral prefrontal cortex (dlPFC) has been found in sex offenders with child victims (SOC) with PD compared to healthy controls, in response to sexual images (Mohnke et al., 2014; Poeppl et al., 2013; Walter et al., 2007). Reduced functional connectivity between the left dlPFC and subcortical regions involved in the processing of sexual information has also been observed in this population (Poeppl et al., 2015). Since the dlPFC is highly implicated in cognitive control and inhibition, including the control and regulation of sexual responses (Ruesink, & Georgiadis, 2017), its reduced activity and functional connectivity with subcortical brain areas might constitute neural signatures of the pedophilic attentional bias.

In light of these findings, it may be hypothesized that increased prefrontal activity could decrease the automatic attention bias for child stimuli in SOC with PD. This possibility can be explored using non-invasive brain stimulation techniques such as transcranial direct current stimulation (tDCS; Brunoni et al., 2012). Through electrodes placed on the scalp, tDCS delivers a weak constant direct current that can enhance or reduce neuronal excitability potentials, with anodal or cathodal stimulation, respectively. Employed as a putative treatment of other disorders characterized by poor cognitive control, such as substance and behavioral addictions, anodal tDCS over the left dlPFC has been found to reduce symptoms immediately after stimulation with a moderate effect size (pooled from studies including single and multiple sessions; Jansen et al., 2013). Notably, a case study has shown that five daily sessions of anodal tDCS of the dlPFC reduced disinhibited sexual responses in a manic patient, albeit in combination with medication (Schestatsky et al., 2013). In healthy participants, acute anodal tDCS of the dlPFC has been found to influence attractiveness ratings for pictures of faces (Ferrari, Lega, Tamietto, Nadal, & Cattaneo, 2015). The effects of other non-invasive brain stimulation techniques on electrocortical and electromyographic markers of sexual arousal have also been examined in prior literature. Schecklmann and colleagues (2015) used Transcranial Magnetic Stimulation (TMS; Hallett, 2000) to study the relationship between sexual motivation and motor preparation in heterosexual and homosexual healthy men. Results indicated that preferred but not non-preferred visual sexual stimuli modulate the excitability of the motor cortex, probed by motor-evoked potentials (MEPs). Prause and associates (2016) used theta burst stimulation (TBS; Lowe, Manocchio, Safati, & Hall, 2011) in heterosexual women and men preoccupied with their sexual risk taking. Results indicated that increased dlPFC excitability can modulate electroencephalographic (EEG)-indexed alpha activity during anticipation and receipt of direct stimulation of the genitalia. However, to the best of our knowledge, no previous study has addressed the possibility of modulating cortical activity during sexual information processing in individuals with PD.

In the current study, we assessed whether acute anodal tDCS of the left dlPFC would modulate attention processes to sexually preferred and non-preferred stimuli in adult males with and without PD. We tested four hypotheses: First (H1), we hypothesized that male SOC with PD would display an automatic attention bias for child stimuli. We operationalized this as shorter response latency, higher response accuracy, and longer viewing times towards child compared to adult target visual stimuli based on eye tracking data. Conversely, teleiophilic controls (i.e., individuals sexually attracted to adults) were expected to show an automatic attention bias for adult targets. Second (H2), in both groups, we hypothesized that acute anodal tDCS over the left dlPFC would reduce the automatic attention bias for sexually preferred stimuli compared to sham tDCS. Third (H3), in both groups, we hypothesized that the tDCS-induced reduction in the automatic attention bias would persist following tDCS (<15min) and generalize to another indirect measure of sexual interest. Lastly (H4), given the functional brain anomalies that have been observed in SOC with PD, we hypothesized that tDCS would have a greater effect in reducing the attentional bias in patients relative to controls.

Method

The present study was approved by the Research Ethics Board of the University of Ottawa's Institute of Mental Health Research, in accordance with the 1964 Declaration of Helsinki. All participants provided written informed consent to their voluntary and anonymous participation in the study. To enhance transparency, facilitate replicability, and prevent positive publication bias, we pre-registered this study on the Open Science Framework before data collection. The pre-registered project, anonymized dataset, annotated scripts for analyses, and output files are publicly available at the project's webpage (osf.io/7udwf).

Participants

Recruitment

The power calculation using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009) indicated that a sample size of 16 participants per group would allow us to achieve 80% statistical power to detect group differences with a large effect size (Cohen's $f = .40$) in a two-factor (tDCS condition [active/anodal vs. sham] * group [PD vs. controls]) analysis of variance (ANOVA) approach, with repeated measures on the tDCS factor, at the conventional type I error rate of 5%. Accordingly, we recruited 16 male SOC, diagnosed with PD and admitting being or having ever been sexually interested in prepubertal children aged 10 or younger, and 16 teleiophilic male controls. Patients were recruited from an outpatient sexual behaviors clinic situated at the Royal Ottawa Mental Health Centre. Patients were either on bail, probation, or parole for contact, noncontact, or both forms of sexual offenses against children <16 years. Before testing, we inspected clinical records to ascertain pertinent information (e.g., penile plethysmography assessments), and we administered a self-report version of the Screening Scale for Pedophilic Interests, Version 2 (SSPI–2; Seto, Stephens, Lalumière, & Cantor, 2015), a behavioral life-history measure designed for SOC. Controls were recruited from the community via online advertising.

Inclusion and Exclusion Criteria

Exclusion criteria for all participants were potential contraindications for tDCS, including prior head injury with loss of consciousness >5min, neurological diagnosis including epilepsy, prior medical conditions with central nervous system sequelae, metallic implants inside the head, electrical medical devices in the body, as well as visual and hearing impairments potentially interfering with testing. Seventeen patients volunteered to participate but had to be screened out. Of note, almost half of them (n = 7/17) reported a history of traumatic brain injury with loss of consciousness >5min, in line with the elevated prevalence of traumatic brain injury often observed among offenders (Farrer & Hedges, 2011). We addressed the presence of *DSM-5* disorders using a semi-structured interview based on questions from the Structured Clinical Interview for *DSM-5*, Research Version (SCID-5, RV; First, Williams, Karg, & Spitzer, 2015). Most patients (n = 11/16) had comorbid depression, often co-occurring with anxiety (n = 7/11). Six patients were medicated with antidepressants and an additional two with leuprolide acetate at the time of testing. For controls, any criminal history (self-reported), a history of any clinically significant psychiatric condition in the last six months, and current psychoactive medication constituted exclusion criteria.

Participant Characteristics

Groups were matched on age, years of education, sexual orientation, hand dominance, and overall attention. Patients were 21 to 65 years old (M = 43.2, SD = 12.8) and controls were 25 to 62 years old (M = 43.4, SD = 10.9). Patients had 8 to 18 years of education (M = 12.00, SD = 3.02) and controls 11 to 15 years (M = 13.07, SD = 1.16). A group difference existed in sexual orientation, as measured with the Kinsey Scale (Kinsey, Pomeroy, Martin, & Sloan, 1948; controls: M = 6.88, SD = 0.34; PD: M = 5.56, SD = 1.82; [$t(16.05) = 2.83$, $p = .01$, $d = 0.10$]). All controls (n = 16) and most patients (n = 12) reported predominant or exclusive sexual attraction to females. The remaining patients reported attraction to males occasionally (n = 3) or exclusively (n = 1). We found no group difference in hand dominance, as assessed with the Edinburgh Handedness Inventory (Oldfield, 1971; [$p > .10$, two-tailed Fisher-Exact-Test]). All participants were right-handed, except for one patient and two controls. We also measured overall attention using the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002) at baseline. Based on reaction times, using the subtraction procedures provided by Fan and colleagues (2009), we obtained four indices of attention. A two-way ANOVA (2 groups [controls vs. PD, as between factor] * 4 indices [alerting, alerting2, orienting, executive control, as within factor]) with mixed design showed no group differences in overall attention [$Q(1, 15.36) = 0.75$, $p = .40$, ξ[1] = .02].

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[1] Explanatory measure of effect size for Yuen's dependent sample trimmed means t-test.

Task Stimuli

Four different picture sets were employed in the present study. The "Virtual People Set" (VPS; Dombert et al., 2013) and the "Not Real People" set (NRP; Pacific Psychological Assessment Cooperation, 2004) included images of computer-generated individuals, clothed/in swimsuits or nude, and varying in terms of Tanner stage of sexual maturity (Tanner, 1990). We selected 68 images displaying a complete lack of secondary sex characteristics as child stimuli (Tanner stage I) and 68 images displaying full sexual maturity as adult stimuli (Tanner stages IV and V). We excluded Tanner stages II and III to avoid confounds due to possible hebephilic interests (i.e., sexual attraction to early adolescents). A third picture set was created *ad hoc* and included 160 photographs of individuals wearing swimsuits, available from the internet under universal creative commons license. We selected photographs depicting female and male prepubescent children and adults (respectively ~6-10 and ~20-40 years old, as evaluated by two independent raters) and varying in terms of apparent body mass index and ethnicity. The fourth picture set included 20 neutral images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008), which were used in practice blocks (details below). To control for low-level visual features, we pre-processed the four picture sets separately to match images for luminance and complexity using Matlab® version 2017a, Spectrum, Histogram, Intensity Normalization and Equalization toolbox (SHINE; Willenbockel et al., 2010). We further removed background colors for all but IAPS images used for practice.

Procedure

The study included two testing sessions, during which participants received either active or sham tDCS in a double-blind, within-subject design with block randomization. We asked participants to abstain from alcohol and drugs since the night before testing, as well as from caffeine and nicotine for 3 hours prior to testing. Stimulation was applied using a battery-driven constant-current regulator (Oasis Pro, Edmonton, Alberta, Canada). One conductive saline-soaked rubber electrode, super-imposed on a sponge plate, was placed on the scalp at site F3 (active/anode electrode, 4.4×4.4cm), corresponding to the left dlPFC, according to the 10–20 International System for Electrode Placement. A second electrode was placed on the contralateral supraorbital area (reference/cathode electrode, 5.1×10.2cm). Direct current was increased in a ramp-like fashion over 10s, until reaching 2mA, and similarly decreased at the end of stimulation. Stimulation was maintained for 20 minutes in the active tDCS condition and turned off after 15 seconds in the sham condition. During the experiment, participants sat in a dimly lit and sound-attenuated room, positioned about 60 centimeters from the computer monitor. Research personnel operated the computer and monitored participants from a separate but communicating room. In line with available guidelines (e.g., Brunoni et al., 2011), we also administered a standard in-house Checklist for Adverse Events at the end of each session. The checklist asked participants what type of stimulation they believed they had received, and to rate adverse effects on a scale from 1 (“no symptoms at all”) to 5 (“severe symptoms”).

Measures

While receiving tDCS, participants completed the antisaccade test (Hallett, 1978) and, within 10 minutes following tDCS, they completed a viewing time test (see Figures 1 and 2, respectively). During both tests, participants’ eye movements were recorded using a contactless remote-controlled eye tracking device (SMI RED 250 eye tracker; SensoMotoric Instruments GmBH, Germany). This device recorded the corneal reflection caused by an infrared light, stored coordinates of gaze position on the screen with 250 Hz frequency, automatically excluded blinking or off-screen gazes, and automatically compensated for minor head movements.

[INSERT FIGURES 1 AND 2 ABOUT HERE]

Antisaccade Test

The antisaccade test included 202 trials. One practice block of 10 trials with neutral stimuli was administered before tDCS. The remaining 192 test trials with sexually relevant stimuli from the VPS and NRP picture sets were administered during tDCS. During each test trial, two images appeared on the computer monitor, one of a child and one of an adult. Stimuli were always matched by sex (both females or both males) and sexual relevance (both clothed/in swimsuits or both nude). One of the two stimuli was always surrounded by a cue, namely a white frame. Trials were divided in two types of blocks, which were alternated during each testing session in ABBABA fashion. Instructions were provided at the beginning of each block. In prosaccade blocks, participants were instructed to look towards the stimulus surrounded by the visual cue. In antisaccade blocks, they had to look towards the opposite stimulus. Across trials, the location of the visual cue (left/right) as well as the age (child/adult) and sex (female/male) of the target was counterbalanced. We created two versions of the test, with different combinations of images and counterbalanced block order, for use in the two testing sessions. Every image was presented 6 times in the whole experiment. Each trial began with a blank screen for 1700-2300ms (average: 2000ms) followed by a fixation cross, presented at the center of the screen for 1250-1750ms (average: 1500ms). Then, two stimuli were presented for 2000-2500ms (average: 2250ms). The entire test took approximately 25 minutes to complete, including short breaks (<1min) between blocks. Based on participant’s eye movements, we extracted two outcome measures: response latency (i.e., time from stimuli appearance to first fixation towards target), and response accuracy (i.e., accuracy of first fixation).

Viewing Time Test

The viewing time test consisted of 80 trials divided in 4 blocks of 20 trials. During each trial, participants viewed an image selected from the swimsuit picture set. Images were presented to the left or the right side of the screen in a randomized fashion. Participants had to indicate the location of each image, by pressing either a left or a right key on the keyboard. Across trials, the age (child/adult) and sex (female/male) of the target was counterbalanced. We created two versions of the test, one per testing session, using a different set of images, so that every image was presented once in the whole experiment. Each trial began with blank screen, presented for 1250-1750ms (average: 1500ms) and followed by a central fixation cross (1700-2300ms, average: 2000ms). Then, a target stimulus was shown until the participant responded (right or left presentation). Completing the test took approximately 10 minutes, including short breaks (<1min) between blocks. Participant's response times were used as a proxy of viewing times.

Statistical Analyses

Before statistical analyses, we removed outliers, defined as values of mean > $\pm$3 SDs, for each outcome measure. Then, we calculated the average proportion of missing data for the antisaccade test across participants and ensured that no one had a proportion > $\pm$3 SDs than this value. No missing data existed in the viewing time test, which required a response to each trial.

We tested H1 with a three-way ANOVA (2 groups [PD vs. controls, as between-subjects factor] * 2 self-reported sexual preferences [preferred vs. non-preferred] * 2 blocks [prosaccade vs. antisaccade]) with mixed design on response latency and accuracy from the antisaccade test, and a two-way ANOVA (2 groups [PD vs. controls, as between-subjects factor] * 2 self-reported sexual preferences [preferred vs. non-preferred]) with mixed design on viewing times.

Next, for each participant, we calculated the difference in outcome measures (i.e., response latency and accuracy from the antisaccade test, viewing times from the viewing time test) between trials with sexually preferred and non-preferred targets for each of the sham and active tDCS conditions. Sexual preference was determined in terms of both gender and age, based on self-reports. The three resulting difference measures were used as indices of automatic attention bias. To test the remaining hypotheses (H2 through H4), we performed a mixed two by two (2 groups [PD vs. controls] * 2 tDCS conditions [active vs. sham]) ANOVA, with repeated measures on the tDCS factor, on the three indices of automatic attention bias. Specifically, to test H2, we compared the indices based on response latency and accuracy during active vs. sham tDCS. To test H3, we further compared the index based on viewing times following active vs. sham tDCS. Robust estimation was used for this index as its values were not normally distributed (Wilcox, 2012). To test H4, we inspected group differences in the effect of active vs. sham tDCS on the three indices. We inspected other effects associated with tDCS by performing a two-way ANOVA (2 groups [controls vs. PD, as between factor] * 2 tDCS conditions [active vs. sham]) with mixed design on the adverse events measured with the Checklist for Adverse Events.

Software

We used the software BeGaze version 3.0 (SensoMotoric Instruments GmbH, Germany) to program and administer the antisaccade and viewing time tests, and E-prime professional version 2.0 (Psychology Software Tools, Pittsburgh, PA) for the ANT. Statistical analyses were performed in the *R* environment for statistical computing, version 3.6.0 (*R* Core Team, 2016), using the packages effsize, version 0.7.6 (Torchiano, 2019), emmeans, version 1.4.3.01 (Russell, 2019), ez, version 4.4-0 (Lawrence, 2016), nlme version 3.1-139 (Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2019), and WRS2, version 1.0-0 (Mair & Wilcox, 2019).

Results

Automatic Attention Bias

We performed the first set of ANOVAs on the outcome measures collected during the sham tDCS condition to address the presence of an automatic attention bias for child targets in patients and for adult targets in controls. Across groups, we expected a main effect of sexual preference indicating response facilitation (i.e., shorter latencies, increased accuracy, and longer viewing times) with self-reported sexually preferred vs. non-preferred targets.

Antisaccade Test

With respect to latency, only the main effect of block type achieved statistical significance [$F(1, 30) = 22.21$, $p < .001$, $\eta^2 = .06$, $\eta_p^2 = .43$] with shorter latencies in prosaccade relative to antisaccade blocks. We found no main effect of sexual preference [$F(1, 30) = 0.45$, $p = .51$, $\eta^2 < .00$, $\eta_p^2 = .01$] but we noted a trend for a main effect of group [$F(1, 30) = 3.18$, $p = .08$, $\eta^2 = .08$, $\eta_p^2 = .10$] as well as a trend for a group * sexual preference interaction [$F(1, 30) = 2.64$, $p = .11$, $\eta^2 = .01$, $\eta_p^2 = .08$]. Even though post-hoc comparisons were insignificant, inspecting mean values (see Table 1) indicated that, across blocks, patients responded slightly faster to child vs. adult targets, in line with the presence of an automatic attention bias. However, contrary to what was expected, controls also responded faster to child vs. adult stimuli.

Regarding accuracy, we observed again a main effect of block [$F(1, 29) = 6.19$, $p = .02$, $\eta^2 = .02$, $\eta_p^2 = .18$], with increased accuracy in prosaccade vs. antisaccade blocks and, additionally, we found a main effect of group [$F(1, 29) = 4.81$, $p = .04$, $\eta^2 = .11$, $\eta_p^2 = .14$], with increased accuracy in controls vs. patients. Although no main effect of sexual preference emerged [$F(1, 29) = 0.04$, $p = .85$, $\eta^2 < .00$, $\eta_p^2 < .00$] the group * sexual preference interaction was statistically significant [$F(1, 29) = 4.38$, $p = .05$, $\eta^2 = .01$, $\eta_p^2 = .13$]. As with latency, post-hoc comparisons were insignificant. Inspection of mean values (see Table 1) indicated that patients were slightly more accurate with child vs. adult targets, consistent with an automatic attention bias, but controls were also slightly more accurate with child vs. adult targets.

Viewing Time Test

There was no main effect of group [$F(1, 30) = 1.10$, $p = .75$, $\eta^2 < .00$,$\eta_p^2 < .00$], sexual preference [$F(1, 30) = 1.65$, $p = .21$, $\eta^2 < .00$,$\eta_p^2 = .05$], or group * sexual preference interaction [$F(1, 30) = 0. 04$, $p = .83$, $\eta^2 < .00$, $\eta_p^2 < .00$] on viewing times. Nonetheless, based on a qualitative description (see Table 1), both patients and controls gazed longer at preferred compared to non-preferred targets, consistent with the expected automatic attention bias.

[INSERT TABLE 1 ABOUT HERE]

Transcranial Direct Current Stimulation (tDCS) Effects

Antisaccade Test

The second set of ANOVAs addressed the impact of active vs. sham tDCS on indices of automatic attention bias. Across groups, we expected reduced bias during (H2) and following (H3) active vs. sham tDCS, as well as a larger reduction in patients compared to controls (H4).

Regarding the latency index, we found no main effect of group [$F(1, 30) = 1.79$, $p = .19$, $\eta^2 = .02$, $\eta_p^2 = .06$] or tDCS condition [$F(1, 30) = 0.12$, $p = .73$, $\eta^2 < .00$, $\eta_p^2 < .00$]. Nevertheless, we observed a significant group * tDCS condition interaction [$F(1, 30) = 4.68$, $p = .04$, $\eta^2 = .09$, $\eta_p^2 = .14$]. Although post-hoc comparisons were insignificant, inspecting mean values (see Table 2) indicated that active vs. sham tDCS reduced the expected bias for child vs. adult targets in patients and it similarly reduced the unexpected bias for child vs. adult targets in controls.

With respect to the accuracy index, we observed a main effect of group [$F(1, 29) = 8.91$, $p = .01$, $\eta^2 = .12$, $\eta_p^2 = .24$], consistent with the presence of a bias for preferred targets in patients and non-preferred targets in controls. No main effect of tDCS condition [$F(1, 29) = 0.69$, $p = .41$, $\eta^2 = .01$, $\eta_p^2 = .02$] or group * tDCS condition interaction [$F(1, 29) = 0.18$, $p = .67$, $\eta^2 < .00$, $\eta_p^2 = .01$] emerged. Also, no post-hoc comparison achieved statistical significance. Inspecting mean values (see Table 2) indicated that active vs. sham tDCS reduced the expected bias for child vs. adult targets in patients but it had the opposite effect in controls, slightly increasing the unexpected bias for child vs. adult targets.

Viewing Time Test

The ANOVA on the viewing time index showed no main effect of group $Q(1, 17.92) = 0.14$, $p = .71$, $\xi = .06$], tDCS condition [$Q(1, 15.92) = 0.06$, $p = .82$, $\xi = .04$], or group * tDCS condition interaction [$Q(1, 15.92) = 0.39$, $p = .54$, $\xi = .06$]. Inspecting mean values (see Table 2) suggested that, across groups, the automatic attention bias for sexually preferred vs. non-preferred targets marginally increased following active relative to sham tDCS.

[INSERT TABLE 2 ABOUT HERE]

Neuromodulation Measures

The ANOVA of the Checklist for Adverse Events showed a main effect of group [$F(1, 28) = 6.94$, $p = .01$, $\eta^2 = .13$, $\eta_p^2 = .20$], with controls reporting more adverse effects than patients, and a main effect of tDCS condition [$F(1, 28) = 6.24$, $p = .02$, $\eta^2 = .08$, $\eta_p^2 = .18$], with participants reporting more adverse effects after active vs. sham tDCS. The percentage of correct guesses was significantly higher in the active than sham condition (68% vs. 33%, $p = .02$, two-tailed Fisher-Exact-Test), indicating incomplete blinding. Nonetheless, no group was more accurate than the other in guessing the tDCS condition ($p > .10$, two-tailed Fisher-Exact-Test).

Discussion

PD is a source of distress for patients and a risk factor for child sexual offending. Hence, the development of successful evidence-based therapeutic interventions is crucial. A growing body of evidence has shown that SOC with PD display an automatic attention bias for child stimuli (e.g., Fromberger et al., 2013) as well as decreased activity and disrupted connectivity profiles in brain areas involved in cognitive control over sexual responses (for a review, see Tenbergen et al., 2015). In light of this evidence, this pre-registered pilot study was the first to explore the effects of acute tDCS on attention bias to sexually relevant stimuli in SOC with PD.

Modest Support for the Pedophilic Automatic Attention Bias

First, we examined the presence of an automatic attention bias for child vs. adult images in SOC with PD and for adult vs. child images in teleiophilic controls (H1). Statistical analyses indicated no main effect of sexual preference on any of the outcome measures. Thus, despite the recruitment of participants being guided by a power analysis, our pilot study might have been statistically underpowered to detect this main effect. Nonetheless, the interaction of group by sexual preference on the antisaccade test was associated with a medium-to-large effect size for response latency and reached significance for response accuracy. From a qualitative standpoint, our results provided partial support for our hypothesis, as patients showed a bias for self-reported sexually preferred stimuli across outcome measures, whereas controls did not. More specifically, patients showed the expected bias for child compared to adult targets during the antisaccade test (i.e., faster and more accurate responses) as well as during the viewing times test (i.e., longer gazing). Control participants also exhibited the expected bias for adult compared to child targets during the viewing times test. However, during the antisaccade test, not only did they show no bias for adult targets, but their responses were consistent with a bias for child targets.

It is highly plausible that the use of different stimuli in the two tasks contributed to such contrasting group trends. In fact, we employed computer-generated images in the antisaccade test, including nude children, and real photographs in the viewing time test (no nudes). Computerized child stimuli might have been sexually attractive for patients because of their previous exposure and attraction to child images, outside of the laboratory, exposure now subject to court-mandated restrictions. Thus, the observed bias for child targets found in patients likely reflected their sexual preference. For controls, computerized adult stimuli might not have been as sexually attractive, whereas computerized child stimuli might have been particularly odd or distressing and, therefore, salient in a non-sexual manner. As a result, the observed bias for child targets found in controls likely reflected an unwanted artefact rather than their sexual preference. Nevertheless, since we did not ask participants to rate stimuli in terms of valence and arousal, we could not directly address this possibility.

It is also conceivable that one of the two tasks was more apt than the other to detect an automatic attention bias, thus explaining some of the inconsistency between outcome measures. Both the antisaccade test (Oberlader, Ettinger, Banse, & Schmidt, 2016) as well as viewing time-based measures (Schmidt et al., 2016) have been successfully employed in the indirect assessment of sexual interest. However, other protocols, such as the Choice Reaction Time task (CRT; Mokros, Dombert, Osterheider, Zappalà, & Santtila, 2010) and the Approach–Avoidance Task (AAT; Weidacker et al., 2017), have also been proposed. Consequently, research directly comparing indirect measures of sexual interest is needed to establish appropriate standards.

Transcranial Direct Current Stimulation for Pedophilic Disorder: A Promising Approach

Next, we aimed to investigate whether, across groups, acute anodal vs. sham tDCS to the left dlPFC could reduce the automatic attention bias for sexually preferred stimuli measured at the antisaccade test (H2). We further predicted that this effect would be greater in patients relative to controls (H3). Since no main effect of sexual preference emerged in the sham condition and, additionally, controls did not show the expected bias for sexually preferred stimuli, we could not address these specific research questions. Therefore, we examined the effect of active vs. sham tDCS on the bias for child targets emerged in both groups. Statistical analyses indicated no main effect of tDCS condition. However, the interaction of group by tDCS condition was associated with a small effect size for response accuracy and reached significance for response latency. From a qualitative perspective, our results partly supported our hypotheses, as active relative to sham tDCS reduced the bias for child targets across outcome measures in patients. For controls, active vs. sham tDCS reduced their bias for child targets based on response latency but increased it based on response accuracy.

In addition to the unexpected trends observed in the control group, methodological factors might have also contributed to the insignificant main effect of tDCS. First, behavioural effects are more reliably observed with repeated rather than single tDCS sessions (Horvath, Forte, & Carter, 2015). Thus, our single administration might have been insufficient to induce statistically meaningful changes. Second, when standard $\leqslant$30s ramp up/down times are used for the sham condition, individuals can often identify active vs. sham tDCS at above chance levels (Wallace, Cooper, Paulmann, Fitzgerald, & Russo, 2016). In line with this, based on participants' self-reports after both sessions, our standard protocol did not ensure completely effective blinding.

Lastly, we addressed whether the reduction in the automatic attention bias expected with active vs. sham tDCS persisted during the viewing time test administered following stimulation (H4). This prediction was not supported, as no significant main or interaction effects emerged after stimulation in either group. Moreover, a qualitative inspection of the data indicated an increased bias towards sexually preferred targets following active vs. sham tDCS across groups.

The insignificant main effect of tDCS may be unsurprising given that single-stimulation effects are known to be short-lived (Stagg & Nitsche, 2011). Some of the already mentioned methodological issues were also at play, such as the confound due to the use of different stimuli and tasks during and after tDCS as well as the imperfect blinding. Importantly, the antisaccade test and the viewing time test might have engaged different brain networks, differently responding to tDCS. Indeed, while performance on the antisaccade test has been repeatedly associated with dlPFC activity (Ettinger et al., 2007; Hutton & Ettinger, 2006), the extent and exact localization of the frontal engagement during the viewing time test is less clear. Therefore, tDCS effects on viewing time-based measured of sexual interest should be further examined.

Limitations and Suggestions for Future Research

Albeit promising, our findings should be interpreted in the context of limitations relating to our sample and methodology. First, when recruiting healthy volunteers, we relied on self-reports of sexual interest. According to available estimates, up to 5% of men in the general population might have a sexual interest in prepubertal children (Seto, 2012). Therefore, we cannot rule out that some control participants concealed a pedophilic interest. Similarly, we cannot rule out potential confounding due to patients being sexually attracted to both children and adults. Indeed, *exclusive* sexual interest in children is very uncommon (Dombert et al., 2016). Second, while we screened for mental health conditions in the control group, we did not exclude comorbid depression and anxiety in the patient group. As a result, altered dlPFC activity, often associated with depression (Koenigs & Grafman, 2009), might have introduced within-group variation modulating the expected tDCS effect. Also, all the patients were involved in some form of cognitive behavioral therapy designed to eliminate PD, which might have further confounded the anticipated tDCS effects. Third, our sample included men only and, conceivably, different results might be expected for women who are sexually attracted to children. Nevertheless, very little is known about the prevalence and features of pedophilia in women (Tenbergen et al., 2015), and even less about potential therapeutic avenues for them. Lastly, all of our patients had a history of sexual offending against children. According to previous research, SOC with PD present reduced inhibitory control compared to men with PD but no offence history (Kärgel et al., 2016; Massau et al., 2017). Thus, impaired inhibitory control might increase the risk of offending, and different levels of impairment might be associated with contact compared to noncontact or no offending. Based on this evidence, our sample of SOC with PD had the highest potential of showing inhibitory impairments and, thus, tDCS-induced improvements. With only 16 patients, however, we were unable to compare those with contact, noncontact, or both kinds of sexual offences. Consequently, future studies should clarify whether tDCS effects vary depending on status (presence/absence) and type of offense, with the ultimate goal to improve patient symptomatology while assisting crime prevention.

Conclusion

The present pre-registered pilot study investigated, for the first time, whether increased prefrontal activity induced by acute anodal vs. sham tDCS could reduce the automatic attention bias for child vs. adult images in SOC with PD. Our results were consistent with the presence of a pedophilic bias across multiple outcome measures in patients and, importantly, suggested a reduction in this bias during active vs. sham tDCS. Controls did not display the expected bias for adult vs. child images, possibly due to the salience of child images capturing their attention in unintended ways. Also, no main or interaction effect persisted immediately following tDCS.

Given the modest yet encouraging preliminary results, we suggested several methodological improvements to inform future research on brain stimulation as a therapeutic aid for PD.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: American Psychiatric Publishing. doi:10.1176/appi.books.9780890425596

Barbaree, H. E., Bogaert, A. F., & Seto, M. C. (1995). Sexual reorientation therapy for pedophiles: Practices and controversies. In L. D. & R. D. McAnulty (Eds.), *The Psychology of sexual orientation, behavior, and identity: A handbook*. (pp. 357-383). Westport, CT: Greenwood.

Brunoni, A. R., Amadera, J., Berbel, B., Volz, M. S., Rizzerio, B. G., & Fregni, F. (2011). A systematic review on reporting and assessment of adverse effects associated with transcranial direct current stimulation. *International Journal of Neuropsychopharmacology*, 14(8), 1133–1145. doi:10.1017/s1461145710001690

Brunoni, A. R., Nitsche, M. A., Bolognini, N., Bikson, M., Wagner, T., Merabet, L., … Fregni, F. (2012). Clinical research with transcranial direct current stimulation (tDCS): Challenges and future directions. *Brain Stimulation*, 5(3), 175–195. doi:10.1016/j.brs.2011.03.002

Dombert, B., Mokros, A., Brückner, E., Schlegl, V., Antfolk, J., Bäckström, A., … Santtila, P. (2013). The Virtual People Set: Developing computer-generated stimuli for the assessment of pedophilic sexual interest. *Sexual Abuse: A Journal of Research and Treatment*, 25(6), 557–582. doi:10.1177/1079063212469062

Dombert, B., Schmidt, A. F., Banse, R., Briken, P., Hoyer, J., Neutze, J., & Osterheider, M. (2016). How common is men's self-reported sexual interest in prepubescent children?. *The Journal of Sex Research*, 53(2), 214-223. doi: 10.1080/00224499.2015.1020108

Ettinger, U., Ffytche, D. H., Kumari, V., Kathmann, N., Reuter, B., Zelaya, F., & Williams, S. C. R. (2007). Decomposing the neural correlates of antisaccade eye movements using event-related fMRI. *Cerebral Cortex*, 18(5), 1148–1159. doi:10.1093/cercor/bhm147

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*, 14(3), 340–347. doi:10.1162/089892902317361886

Farrer, T. J., & Hedges, D. W. (2011). Prevalence of traumatic brain injury in incarcerated groups compared to the general population: A meta-analysis. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, 35(2), 390–394. doi:10.1016/j.pnpbp.2011.01.007

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41(4), 1149–1160. doi:10.3758/brm.41.4.1149

Ferrari, C., Lega, C., Tamietto, M., Nadal, M., & Cattaneo, Z. (2015). I find you more attractive … after (prefrontal cortex) stimulation. *Neuropsychologia*, 72, 87–93. doi:10.1016/j.neuropsychologia.2015.04.024

First, M. B., Williams, J. B. W., Karg, R. S., & Spitzer, R. L. (2015). *Structured clinical interview for DSM-5—Research version (SCID-5 for DSM-5, RV)*. Arlington, VA: American Psychiatric Association.

Fromberger, P., Jordan, K., Steinkrauss, H., von Herder, J., Witzel, J., Stolpmann, G., … Müller, J. L. (2012). Diagnostic accuracy of eye movements in assessing pedophilia. *The Journal of Sexual Medicine*, 9(7), 1868–1882. doi:10.1111/j.1743-6109.2012.02754.x

Fromberger, P., Jordan, K., Steinkrauss, H., von Herder, J., Stolpmann, G., Kröner-Herwig, B., & Müller, J. L. (2013). Eye movements in pedophiles: Automatic and controlled attentional processes while viewing prepubescent stimuli. *Journal of Abnormal Psychology*, 122(2), 587–599. doi:10.1037/a0030659

Fromberger, P., Jordan, K., von Herder, J., Steinkrauss, H., Nemetschek, R., Stolpmann, G., & Müller, J. L. (2011). Initial orienting towards sexually relevant stimuli: Preliminary evidence from eye movement measures. *Archives of Sexual Behavior,* 41(4), 919–928. doi:10.1007/s10508-011-9816-3

Garcia, F. D., Delavenne, H. G., Assumpção, A. de F. A., & Thibaut, F. (2013). Pharmacologic treatment of sex offenders with paraphilic disorder. *Current Psychiatry Reports*, 15(5). doi:10.1007/s11920-013-0356-5

Hallett, P. E. (1978). Primary and secondary saccades to goals defined by instructions. *Vision Research*, 18(10), 1279–1296. doi:10.1016/0042-6989(78)90218-3

Hanson, R. K., & Morton-Bourgon, K. E. (2009). The accuracy of recidivism risk assessments for sexual offenders: A meta-analysis of 118 prediction studies. *Psychological Assessment*, 21(1), 1–21. doi:10.1037/a0014421

Hallett, M. (2000). Transcranial magnetic stimulation and the human brain. *Nature*, 406(6792), 147–150. doi:10.1038/35018000

Holoyda, B. J., & Kellaher, D. C. (2016). The biological treatment of paraphilic disorders: An updated review. *Current Psychiatry Reports*, 18(2). doi:10.1007/s11920-015-0649-y

Horvath, J. C., Forte, J. D., & Carter, O. (2015). Quantitative review finds no evidence of cognitive effects in healthy populations from single-session transcranial direct current stimulation (tDCS). *Brain Stimulation*, 8(3), 535–550. doi:10.1016/j.brs.2015.01.400

Hutton, S. B., & Ettinger, U. (2006). The antisaccade task as a research tool in psychopathology: A critical review. *Psychophysiology*, 43(3), 302–313. doi:10.1111/j.1469-8986.2006.00403.x

Imburgio, M. J., & Orr, J. M. (2018). Effects of prefrontal tDCS on executive function: Methodological considerations revealed by meta-analysis. *Neuropsychologia*, 117, 156–166. doi:10.1016/j.neuropsychologia.2018.04.022

Jansen, J. M., Daams, J. G., Koeter, M. W. J., Veltman, D. J., van den Brink, W., & Goudriaan, A. E. (2013). Effects of non-invasive neurostimulation on craving: A meta-analysis. *Neuroscience & Biobehavioral Reviews*, 37(10), 2472–2480. doi:10.1016/j.neubiorev.2013.07.009

Jordan, K., Fromberger, P., von Herder, J., Steinkrauss, H., Nemetschek, R., Witzel, J., & Müller, J. L. (2016). Impaired attentional control in pedophiles in a sexual distractor task. *Frontiers in Psychiatry*, 7. doi:10.3389/fpsyt.2016.00193

Kagerer, S., Wehrum, S., Klucken, T., Walter, B., Vaitl, D., & Stark, R. (2014). Sex attracts: Investigating individual differences in attentional bias to sexual stimuli. *PLoS ONE,* 9(9), e107795. doi:10.1371/journal.pone.0107795

Kärgel, C., Massau, C., Weiß, S., Walter, M., Borchardt, V., Krueger, T. H. C., … Schiffer, B. (2016). Evidence for superior neurobiological and behavioral inhibitory control abilities in non-offending as compared to offending pedophiles. *Human Brain Mapping*, 38(2), 1092–1104. doi:10.1002/hbm.23443

Kinsey, A. C., Pomeroy, W. B., & Martin, C. E. (1948). Sexual behavior of the human male. *The American Journal of Psychology*, 61(2), 303. doi:10.2307/1416987

Koenigs, M., & Grafman, J. (2009). The functional neuroanatomy of depression: Distinct roles for ventromedial and dorsolateral prefrontal cortex. *Behavioural Brain Research*, 201(2), 239–243. doi:10.1016/j.bbr.2009.03.004

Lang, P.J., Bradley, M.M., & Cuthbert, B.N. (2008). *International affective picture System (IAPS): Affective ratings of pictures and instruction manual*. University of Florida, Gainesville, FL.

Långström, N., Enebrink, P., Lauren, E.-M., Lindblom, J., Werko, S., & Hanson, R. K. (2013). Preventing sexual abusers of children from reoffending: systematic review of medical and psychological interventions. *BMJ*, f4630–f4630. doi:10.1136/bmj.f4630

Lawrence MA. *ez: Easy analysis and visualization of factorial experiments*. R package version 4.4-0. 2013 Available at http://CRAN.R-project.org/package=ez.

Lowe, C. J., Manocchio, F., Safati, A. B., & Hall, P. A. (2018). The effects of theta burst stimulation (TBS) targeting the prefrontal cortex on executive functioning: A systematic review and meta-analysis. *Neuropsychologia*, 111, 344–359. doi:10.1016/j.neuropsychologia.2018.02.004

Massau, C., Tenbergen, G., Kärgel, C., Weiß, S., Gerwinn, H., Pohl, A., … Schiffer, B. (2017). Executive functioning in pedophilia and child sexual offending. *Journal of the International Neuropsychological Society*, 23(6), 460–470. doi:10.1017/s135561771700031

Mair, P., & Wilcox, R. (2019). Robust statistical methods in R using the WRS2 package. *Behavior Research Methods*. doi:10.3758/s13428-019-01246-w

Miler, J. A., Meron, D., Baldwin, D. S., & Garner, M. (2017). The effect of prefrontal transcranial direct current stimulation on attention network function in healthy volunteers. *Neuromodulation: Technology at the Neural Interface*, 21(4), 355–361. doi:10.1111/ner.12629

Mohnke, S., Müller, S., Amelung, T., Krüger, T. H. C., Ponseti, J., Schiffer, B., … Walter, H. (2014). Brain alterations in paedophilia: A critical review. *Progress in Neurobiology*, 122, 1–23. doi:10.1016/j.pneurobio.2014.07.005

Mokros, A., & Banse, R. (2019). The "Dunkelfeld" project for self-identified pedophiles: A reappraisal of its effectiveness. *The Journal of Sexual Medicine*, 16(5), 609–613. doi:10.1016/j.jsxm.2019.02.009

Mokros, A., Dombert, B., Osterheider, M., Zappalà, A., & Santtila, P. (2010). Assessment of pedophilic sexual interest with an attentional choice reaction time task. *Archives of Sexual Behavior*, 39(5), 1081–1090. doi:10.1007/s10508-009-9530-6

Mokros, A., Gebhard, M., Heinz, V., Marschall, R. W., Nitschke, J., Glasgow, D. V., … Laws, D. R. (2013). Computerized assessment of pedophilic sexual interest through self-report and viewing time. *Sexual Abuse: A Journal of Research and Treatment*, 25(3), 230–258. doi:10.1177/1079063212454550

Oberlader, V. A., Ettinger, U., Banse, R., & Schmidt, A. F. (2016). Development of a cued pro- and antisaccade paradigm: An indirect measure to explore automatic components of sexual interest. *Archives of Sexual Behavior*, 46(8), 2377–2388. doi:10.1007/s10508-016-0839-7

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9(1), 97–113. doi:10.1016/0028-3932(71)90067-4

Pacific Psychological Assessment Cooperation (2004). *The Not-Real People Stimulus Set for assessment of sexual interest*. Victoria, BC: Pacific Psychological Assessment Cooperation.

Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team (2019). *nlme: Linear and Nonlinear Mixed Effects Models*. R package version 3.1-139, https://CRAN.R-project.org/package=nlme.

Poeppl, T. B., Eickhoff, S. B., Fox, P. T., Laird, A. R., Rupprecht, R., Langguth, B., & Bzdok, D. (2015). Connectivity and functional profiling of abnormal brain structures in pedophilia. *Human Brain Mapping*, 36(6), 2374–2386. doi:10.1002/hbm.22777

Poeppl, T. B., Nitschke, J., Santtila, P., Schecklmann, M., Langguth, B., Greenlee, M. W., … Mokros, A. (2013). Association between brain structure and phenotypic characteristics in pedophilia. *Journal of Psychiatric Research*, 47(5), 678–685. doi:10.1016/j.jpsychires.2013.01.003

Prause, N., Siegle, G. J., Deblieck, C., Wu, A., & Iacoboni, M. (2016). EEG to primary rewards: predictive utility and malleability by brain stimulation. *PLoS ONE*, 11(11), e0165646. doi:10.1371/journal.pone.0165646

R Core Team (2016). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing. Vienna, Austria.

Ruesink, G. B., & Georgiadis, J. R. (2017). Brain imaging of human sexual response: Recent developments and future directions. *Current Sexual Health Reports*, 9(4), 183–191. doi:10.1007/s11930-017-0123-4

Russell, L. (2019). *emmeans: Estimated Marginal Means, aka Least-Squares Means*. R package version 1.4.3.01. Available at: https://CRAN.R-project.org/package=emmeans

Schecklmann, M., Engelhardt, K., Konzok, J., Rupprecht, R., Greenlee, M. W., Mokros, A., … Poeppl, T. B. (2015). Sexual motivation is reflected by stimulus-dependent motor cortex excitability. *Social Cognitive and Affective Neuroscience*, 10(8), 1061–1065. doi:10.1093/scan/nsu157

Schestatsky, P., Janovik, N., Lobato, M. I., Belmonte-de-Abreu, P., Schestatsky, S., Shiozawa, P., & Fregni, F. (2013). Rapid therapeutic response to anodal tDCS of right dorsolateral prefrontal cortex in acute mania. *Brain Stimulation*, 6(4), 701–703. doi:10.1016/j.brs.2012.10.008

Schmidt, A. F., Babchishin, K. M., & Lehmann, R. J. B. (2016). A meta-analysis of viewing time measures of sexual interest in children. *Archives of Sexual Behavior*, 46(1), 287–300. doi:10.1007/s10508-016-0806-3

Seto, M. C. (2008). *Pedophilia and sexual offending against children: Theory, assessment, and intervention*. American Psychological Association. doi:10.1037/11639-000

Seto, M. C. (2009). Pedophilia. *Annual Review of Clinical Psychology*, *5*, 391-407. doi:10.1146/annurev.clinpsy.032408.153618

Seto, M. C. (2012). Is pedophilia a sexual orientation? *Archives of Sexual Behavior*, 41(1), 231–236. doi:10.1007/s10508-011-9882-6

Seto, M. C. (2013). *Internet sex offenders*. American Psychological Association. doi:10.1037/14191-000

Stagg, C. J., & Nitsche, M. A. (2011). Physiological basis of transcranial direct current stimulation. *The Neuroscientist*, 17(1), 37–53. doi:10.1177/1073858410386614

Tanner, J. M. (1990). *Foetus into man: Physical growth from conception to maturity.* Harvard University Press.

Tenbergen, G., Wittfoth, M., Frieling, H., Ponseti, J., Walter, M., Walter, H., … Kruger, T. H. C. (2015). The neurobiology and psychology of pedophilia: Recent advances and challenges. *Frontiers in Human Neuroscience,* 9. doi:10.3389/fnhum.2015.00344

Torchiano, M. (2019). *effsize: Efficient Effect Size Computation*. R package version 0.7.6. Available at: https://CRAN.R-project.org/package=effsize

Wallace, D., Cooper, N. R., Paulmann, S., Fitzgerald, P. B., & Russo, R. (2016). Perceived comfort and blinding efficacy in randomised sham-controlled transcranial direct current stimulation (tDCS) trials at 2 mA in young and older healthy adults. *PLoS ONE*, 11(2), e0149703. doi:10.1371/journal.pone.0149703

Walter, M., Witzel, J., Wiebking, C., Gubka, U., Rotte, M., Schiltz, K., … Northoff, G. (2007). Pedophilia is linked to reduced activation in hypothalamus and lateral prefrontal cortex during visual erotic stimulation. *Biological Psychiatry*, 62(6), 698–701. doi:10.1016/j.biopsych.2006.10.018

Weidacker, K., Kärgel, C., Massau, C., Weiß, S., Kneer, J., Krueger, T. H. C., & Schiffer, B. (2017). Approach and avoidance tendencies toward picture stimuli of (pre-)pubescent children and adults. *Sexual Abuse: A Journal of Research and Treatment,* 107906321769713. doi:10.1177/1079063217697134

Wilcox, R. (2012). *Introduction to robust estimation and hypothesis testing (3rd ed.).* Elsevier. doi:10.1016/c2010-0-67044-1

Willenbockel, V., Sadr, J., Fiset, D., Horne, G., Gosselin, F., & Tanaka, J. (2010). The SHINE toolbox for controlling low-level image properties. *Journal of Vision,* 10(7), 653–653. doi:10.1167/10.7.653

Zhao, M., Gersch, T. M., Schnitzer, B. S., Dosher, B. A., & Kowler, E. (2012). Eye movements and attention: The role of pre-saccadic shifts of attention in perception, memory and the control of saccades. *Vision Research*, 74, 40–60. doi:10.1016/j.visres.2012.06.017

Tables

Table 1

Mean Response Latency, Accuracy, and Viewing Times for Preferred and Non-preferred Targets

	Response Latency		Response Accuracy		Viewing times	
	Preferred	Non-preferred	Preferred	Non-preferred	Preferred	Non-preferred
Patients (*n* = 16)	345.68 (92.31)	354.73 (68.09)	80 (0.18)	78 (0.16)	439.33 (103.64)	432.72 (85.77)
Controls (*n* = 16)	405.27 (89.09)	383.58 (73.22)	87 (0.11)	90 (0.09)	430.47 (93.88)	421.23 (79.44)

Note: Response latency and viewing times are measured in ms, response accuracy in percentage of correct responses. Standard deviations are reported in parentheses. Preference is defined in terms of both sex and age.

Table 2

Transcranial Direct Current Stimulation Effects on the Indices of Attentional bias

	Latency Index		Accuracy Index		Viewing Times Index	
	Sham	Active	Sham	Active	Sham	Active
Patients (*n* = 16)	-13.21 (59.00)	6.72 (27.70)	2.40 (8.30)	0.14 (5.12)	6.60 (40.61)	9.41 (28.52)
Controls (*n* = 16)	22.57 (40.50)	-4.90 (23.57)	-3.08 (5.91)	-3.81 (6.91)	9.24 (28.00)	47.67 (136.26)

Note: Indices were computed as the difference in outcome measures (i.e., response latency, response accuracy, and viewing times) between trials with targets congruent and incongruent with each participant's self-reported sexual preferences for sex and age. An automatic attention bias for sexually preferred targets is indicated by a negative index value for latency and by a positive index value for accuracy and viewing times. Response latency and viewing times are measured in ms, response accuracy in percentage of correct responses. Standard deviations are reported in parentheses. Active = active tDCS condition, Sham = sham (placebo) tDCS condition.

Figures

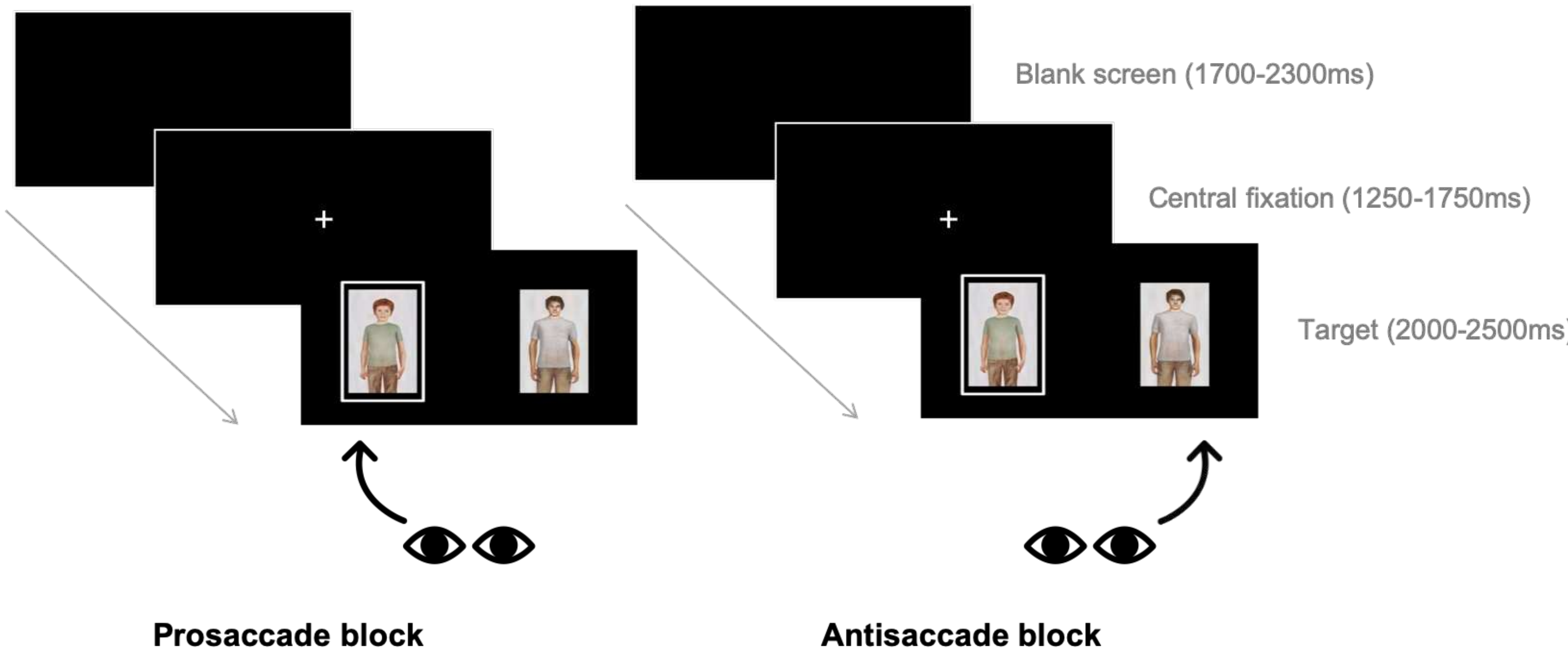

Figure 1. Antisaccade test. The computerized antisaccade test was performed during active and sham transcranial Direct Current Stimulation. To complete test trials, participants had to look at either of two computer-generated images of clothed and nude female and male children (Tanner stage I) and adults (Tanner stages IV and V) simultaneously appearing on the computer monitor. The test included two types of blocks: prosaccade and antisaccade, during which participants were instructed to look, respectively, towards the image marked by a visual cue (white frame) or towards the other image. Responses were collected using an eye-tracking device.

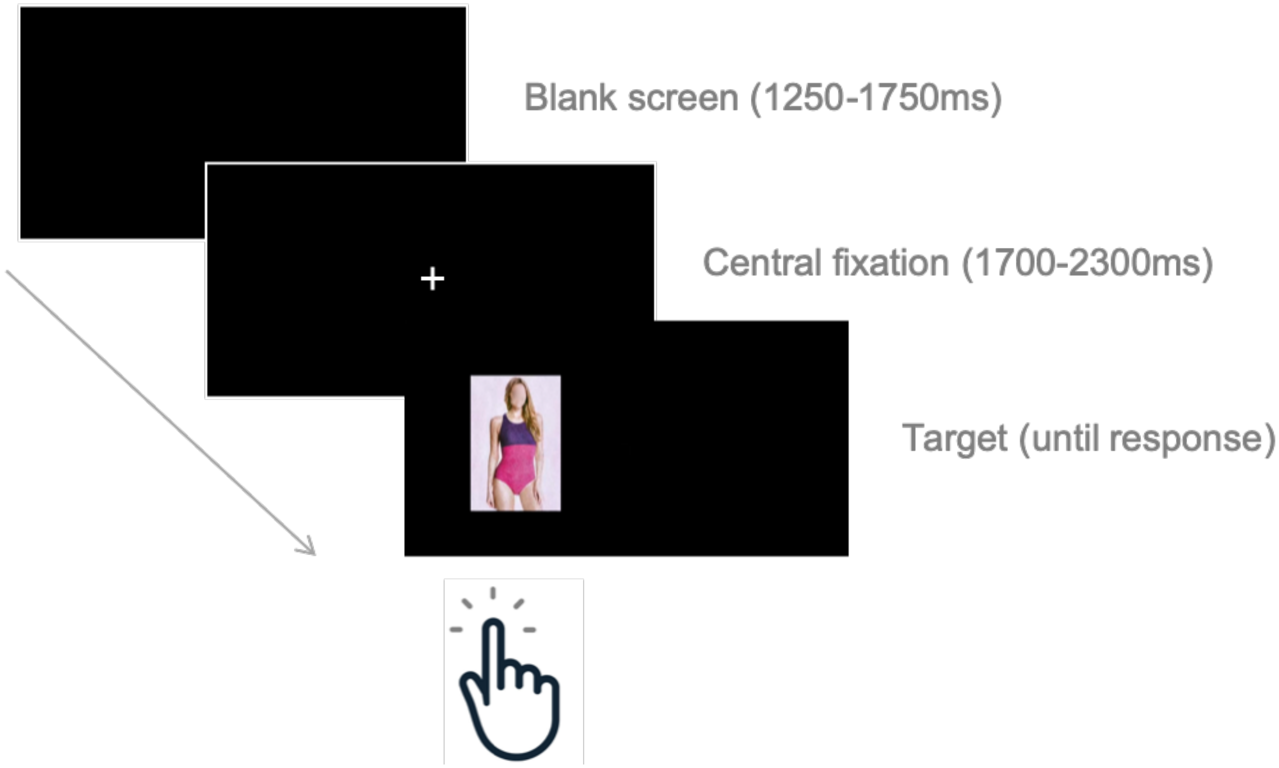

Figure 2. Viewing time test. The viewing time test was performed within the 10 minutes following active and sham transcranial Direct Current Stimulation. To complete the test, participants had to indicate the location (left vs. right) where advertising photographs of female and male children (aged ~6-10) and adults (aged ~20-40) wearing swimsuits appeared, by pressing one of two keys on the computer keyboard. Faces were visible to participants but have been blurred for publication.